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Indian Standard

METHODS OF MEASUREMENT OF CURRENT NOISE GENERATED IN FIXED RESISTORS

(First Reprint JULY 1983)

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INDIAN STANDARDS INSTITUTION
MANAK BHAVAN, 9 BAHADUR SHAH ZAFAR MARG
NEW DELHI 110002

Gr 4 *August* 1969

Indian Standard
METHOD OF MEASUREMENT OF CURRENT NOISE GENERATED IN FIXED RESISTORS

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Indian Standard

METHOD OF MEASUREMENT OF CURRENT NOISE GENERATED IN FIXED RESISTORS

0. FOREWORD

0.1 This Indian Standard was adopted by the Indian Standards Institution on 21 February 1969, after the draft finalized by the Capacitors and Resistors for Electronic Equipment Sectional Committee had been approved by the Electrotechnical Division Council.

0.2 The method of measurement described in this standard applies to all classes of fixed resistors used in circuits where current noise is critical, for example, in some low-signal-level audio and other low-frequency circuits. It constitutes a description of the measurement system and procedures recommended for use in assessing the ' noisiness ' or magnitude of current noise generated in fixed resistors of any given type and does not cover acceptable limiting values of current noise.

0.3 The details of a current noise measuring set-up are given for guidance and information in Appendix A. Attempts are being made to develop an indigenous measuring set-up to measure the current noise. It is expected that publication of this standard would enable development of such indigenous set-up.

0.4 Assistance has been derived from the following while preparing this standard:

Publication No. 195 Method of measurement of current noise generated in fixed resistors. International Electrotechnical Commission.

Draft B. S. Document No. 66/2219 Method of measurement of current noise generated in fixed resistors. British Standards Institution.

0.5 For the purpose of deciding whether a particular requirement of this standard is complied with, the final value, observed or calculated, expressing the result of a test, shall be rounded off in accordance with IS : 2-1960*. The number of significant places retained in the rounded off value should be the same as that of the specified value in this standard.

---

*Rules for rounding off numerical values (*revised*).

1. SCOPE

1.1 This standard specifies a method of measurement and the associated test conditions for use in the determination of the magnitude of current noise generated in fixed resistors.

1.1.1 Limiting values of the magnitude of current noise for acceptable performance are not specified.

2. TERMINOLOGY

2.0 For the purpose of this standard, the following definitions shall apply.

2.1 Noise Voltage — A spontaneous fluctuating voltage having instantaneous amplitude values which, because they are distributed in a random manner, cannot be predicted except in terms of probability statements.

NOTE — Usually the amplitude characteristic of principal interest is not the instantaneous value but the 'time-averaged' value. The measurement of amplitude commonly used and adopted for this standard is the root of the mean-square value of voltage (rms) transmitted in a particular frequency pass band.

2.2 Thermal Noise Voltage — A fluctuating voltage caused by random motion of thermally agitated charges, present in all resistors.

NOTE 1 — It is not necessary to determine the magnitude of thermal noise by measurement because the mean-square value of the fluctuating voltage appearing at the open-circuit terminals of a resistor, which would be indicated by the measuring system, may be calculated using Nyquist's equation:

$$\overline{V_n^2} = 4\,k\,T\,R\,\Delta f$$

where

k = Boltzmann's constant, 1·38 × 10^{-23} watt seconds per degree Kelvin;

T = the absolute temperature in degrees Kelvin;

R = the resistance value in ohms; and

Δf = the effective pass band of the measuring system in cycles per second.

NOTE 2 — A resistor may be represented as a thermal noise source having a zero impedance noise voltage generator connected in series with a noise-free resistor (*see* Fig. 1).

NOTE 3 — Although this standard is concerned with measurement of current noise in resistors, the presence of thermal noise cannot be ignored because thermal noise of the resistor under test is frequently a major source of interference in the measurement.

2.3 Current Noise Voltage — The increase in the noise voltage over the thermal noise voltage resulting from a direct current flowing in a fixed resistor.

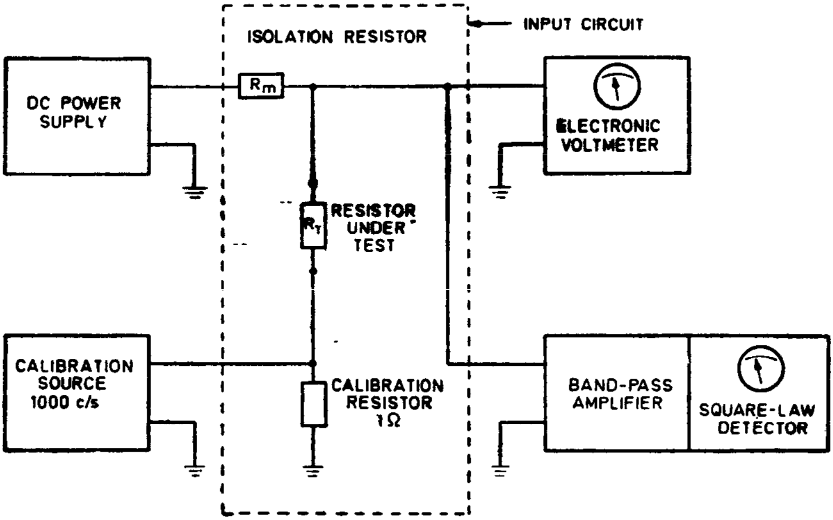

FIG. 1 BLOCK DIAGRAM OF CURRENT NOISE MEASURING SET-UP

NOTE 1 — A resistor exhibiting current noise may be represented as a nois source having a zero-impedance current noise voltage generator connected i series with an independent (that is, a non-coherent) thermal noise voltag generator and noise-free resistor.

NOTE 2 — The mean-square value of current noise voltage per unit pass ban varies substantially inversely with frequency. If the mean-square voltage inversely proportional to frequency, then ideal rectangular pass bands havin equal ratios of upper to lower band-pass limits transmit equal magnitudes noise voltage from a given noise source.

2.4 Current Noise Index — The term used to express the 'noisiness' individual resistors in 'microvolts-per-volt in-a-decade' expressed in d The ideal rectangular pass band associated with the current noise ind is one frequency decade, geometrically centred at 1 000 c/s.

The index is defined as follows:

$$\text{Current noise index} = 20 \log_{10} \frac{v_{rms}}{V_T} \text{ dB (in a frequency decad}$$

Where v_{rms} is the number of microvolts of open-circuit r current noise voltage in a frequency decade and V_T is the number of dc volts applied to the resistor under test.

NOTE — Since the current noise power spectrum approximates to a $1/f$ frequency characteristic, the index provides an estimate of current noise in any frequency decade.

3. DETERMINATION OF CALIBRATION VOLTAGE

3.1 The correct magnitude of calibration voltage produces a deflection in the output indicator (*see* **A-2.2**) equal to that produced by a current noise voltage generator having an rms value of one millivolt in a frequency decade. The calibration voltage should produce a meter reading equivalent to +60 dB when the measuring system is calibrated.

3.1.1 The calibration voltage is calculated using the following equation:

$$V_{cal} = \sqrt{\frac{A}{\log_e 10}} = 0{\cdot}659\sqrt{A}\ \text{mv}$$

The term A represents the expression $\log_e f_2/f_1$ in the case of an ideal pass band with upper and lower frequency limits of f_2 and f_1 respectively. The value for A for any particular band-pass amplifier is computed as described below:

> The gain versus frequency is measured throughout the pass band of the system. The gain is given by the square of the ratio of the output voltage, as indicated by the output meter, to the input voltage, applied across the terminals of the calibration resistor.
>
> The ratios of the gains at the various frequencies to the gain at the calibration frequency are then calculated. Finally, these gain ratio values are divided by their respective frequencies, in cycles per second and the resulting values plotted against frequency using linear graph paper. The area under the resulting curve equals A and should have a value close to unity. The accuracy of determination of area of A shall be within ±2·5 percent.

The calibration source shall be adjusted to provide at the terminals of the calibration resistor, a voltage with an rms value within ±2 percent of the calculated value.

An independent means for checking the accuracy of the noise measuring system, using thermal noise, is given in **6.3.1**.

4. MEASUREMENT PROCEDURE

4.0 The complete operation consists of the following consecutive steps (*see also* Appendix A):

a) Calibration,

b) Measurement of system noise,

c) Measurement of total noise with the simultaneous measurement of the dc voltage across the resistor under test, and

d) Computation of current noise index.

4.0.1 Considerable saving of time can be achieved when groups of 'identical' resistors are to be measured by taking advantage of the stability of the particular test equipment. The intervals with which the calibration and system noise measurements should be repeated will be dependent on the stability of the equipment and on the accuracy required.

4.1 Calibration — The resistor to be tested is inserted in the test jig and the appropriate isolation resistor (*see* Table 1), switched into the circuit. The function switch is set to 'calibrate' and the gain control adjusted so that the noise voltage meter indicates +60 dB or its equivalent.

4.2 Measurement of System Noise — The function switch is set to 'system noise'. After a delay of 5 to 6 seconds, to allow the meter to reach a representative mean value, the system noise (S) is read in decibels.

4.3 Measurement of Total Noise — The function switch is set to 'total noise' so that dc voltage is applied to the resistor under test. The dc voltage is then adjusted to the required value. After a delay of 5 to 6 seconds, the dc voltage (D) in decibels, and the total noise (T) in decibels, are read.

4.4 Computation of the Current Noise Index — The current noise index is computed from the above three measured quantities S, T, and D.

$$\text{Current noise index} = T - f(T - S) - D$$

4.4.1 Values of $f(T-S)$ as a function of $(T-S)$ are given in Table 1. When the difference $(T-S)$ exceeds 15 dB, $f(T-S)$ is essentially zero and may be ignored.

5. ACCURACY

5.1 Accuracy of the noise voltage measurement shall be ± 0·75 dB. The accuracy of determinations of the current noise index shall be

±1 dB when the current noise is large compared to system noise, that is, $T-S$ (*see* **4**) is greater than 15 dB.

TABLE 1 CORRECTION FACTOR FOR PRESENCE OF 'SYSTEM NOISE'

(*Clauses* 4.1 *and* 4.4.1)

$T-S$ (1)	$f(T-S)$ Correction Factor (2)	$T-S$ (1)	$f(T-S)$ Correction Factor (2)	$T-S$ (1)	$f(T-S)$ Correction Factor (2)
dB		dB		dB	
Less	—	3·8	2·3	7·0	0·9
than 1*	—	3·9	2·2	to	
1·0	6·9	4·0	2·2	7·3	
1·1	6·5	4·1	2·1	7·4	0·8
1·2	6·2	4·2	2·0	to	
1·3	5·9	4·3	2·0	7·9	
1·4	5·6	4·4	1·9	8·0	0·7
1·5	5·3	4·5	1·9	to	
1·6	5·1	4·6	1·8	8·5	
1·7	4·9	4·7	1·8	8·6	0·6
1·8	4·7	4·8	1·7	to	
1·9	4·5	4·9	1·7	9·3	
2·0	4·3	5·0	1·6	9·4	0·5
2·1	4·1	5·1	1·6	to	
2·2	3·9	5·2	1·5	9·9	
2·3	3·8	5·3	1·5	10·0	0·4
2·4	3·6	5·4	1·4	to	
2·5	3·5	5·5	1·4	11·5	
2·6	3·4	5·6	1·4	11·6	0·3
2·7	3·3	5·7	1·3	to	
2·8	3·2	5·8	1·3	12·7	
2·9	3·1	5·9	1·3	12·8	0·2
3·0	3·0	6·0	1·2	to	
3·1	2·9	6·1	1·2	14·5	
3·2	2·8	6·2	1·2	14·6	0·1
3·3	2·7	6·3	1·1	to	
3·4	2·6	6·4	1·1	15·0	
3·5	2·5	6·5	1·0		
3·6	2·4	to			
3·7	2·4	6·9			

*Report current noise index as less than ($T-7-D$) dB.

5.2 Since the accuracy of determinations of the current noise index deteriorates as the measured values of total noise approach the values of system noise, it is not recommended that the system be used for accurate determinations of the index when $T-S$ (*see* **4**) is less than 1·0 dB. However, it is possible to state a maximum value for the index in such cases.

$$\text{Current noise index} < T - 7 - D$$

when $(T - S) < 1$ dB.

5.3 It is not uncommon for certain resistors to exhibit noise measurement variations greater than 0·75 dB. It should therefore be recognized that lack of agreement of repeated measurements on such resistors does not necessarily reflect a loss of accuracy of the measuring system but is an indication of a noise property of the resistor.

6. PRECAUTIONS

6.0 There are a number of precautions that should be taken in the construction and use of the current noise test equipment.

6.1 Precautions in the Construction of Equipment

6.1.1 *Shielding* — Good shielding practice shall be adopted in the construction of equipment. Since the input circuit operates at extremely low signal levels, it is necessary that all parts and leads in the input circuit be very well shielded. Components carrying large signals should not be located near the input circuit.

6.1.2 *Input Impedance* — The impedance, being in parallel with R_m and also in parallel with the resistor under test, attenuates the noise signals. This impedance in the frequency range of 600 to 1 600 c/s should therefore be greater than 4 megohms. The inter-lead and lead-to-ground capacities of the resistor under test and of the input to the ac band-pass amplifier should be minimized by the use of short leads, adequate spacing and careful mounting.

6.2 Precautions in the Use of Equipment

6.2.1 *Location* — Reasonable precautions such as are commonly associated with sensitive measurements should be followed in operating the test set. The operating location should be free of strong magnetic and electric fields and of sources of electro-magnetic radiation. Ordinarily, it need not be operated in a screened room. The location should be free from strong mechanical vibrations and from sources of loud sound. These precautions are mentioned to serve as a guide in selecting suitable locations. The suitability of a location can be determined by comparing test set performance in the selected location with that obtained in a 'quiet' location. Usually, sources of interference are readily identifiable.

6.2.2 *Ambient Conditions* — The equipment and resistors to be tested should be stabilized at an ambient temperature between 20° to 30°C and less than 60 percent RH for at least 24 hours before testing.

6.3 Performance Checks — Two types of performance checks are recommended. The first depends upon the measurement of instrument and thermal noise while the other involves repeated measurement of specific resistors.

6.3.1 *Performance Check by Measurement of Instrument and Thermal Noise* — The function switch is turned to 'calibrate' and the R_T terminals are short-circuited. The gain is then adjusted to the 'calibrate line' and left at that position for the remainder of the test. The function switch is then turned to 'system noise' and the noise read. The short circuit is then removed and the indicated noise read for each value of R_m. The readings should fall within the following limits:

R_m ohms	*Actual* R_T	*Permissible Limits of System Noise Reading* dB
Any	Short-circuit	Below −5
1 K	Open	−9 to −4·5
10 K	Open	−5 to −2
100 K	Open	+5 to +7·5
1 M	Open	+14 to +18

Note — Gain should be set to 'calibrate line' with R_T short circuited.

The first readings are essentially measurements of the noise in the amplifier. The last two readings are essentially measurements of thermal noise of R_m in the pass band of the instrument. The third reading is influenced by both factors.

6.3.2 *Performance Check by Comparison of Repeated Measurements* — A feasible means of monitoring the stability of operation of the equipment is to keep a record of the measurements made on a group of "control" resistors. It is desirable for the control group to consist of different types of resistors and represent a large range of resistance and current noise values. Plotting the data *vs* time in the form of a control chart is suggested as a simple and effective means for displaying irregularities.

APPENDIX A

(*Clause* 0.3)

TYPICAL CURRENT NOISE MEASURING SET-UP

A-0. GENERAL

A-0.1 The details of a typical current noise measuring set-up, the use of which is made in this standard in measuring the current noise generated in fixed resistors, are described in this Appendix.

Note — The measuring set-up described is based on the Quantec instrument which may be made use of in measuring the current noise in resistors.

A-1. MEASURING SET-UP

A-1.1 The noise measuring system may be considered as consisting of three sections: the input circuit, the dc system and the ac system.

A-1.2 Input Circuit — The input circuit consists of the isolation resistor (R_m), the resistor under test (R_T), and the calibration resistor, as shown in Fig. 1.

A-1.3 The isolation resistor is required to reduce the shunting effect of the dc supply system to the noise in the resistor under test. A number of isolation resistors will be needed to cover the range of resistance values of the resistors under test and these can be switched into the circuit as required. A minimum of four isolation resistors is required for meeting the measurement conditions specified in Table 1. These resistors shall be current noise free.

A-1.4 The resistor under test shall be mounted in a suitable test jig shielded from external fields.

A-1.5 The calibration resistor shall be current noise free and shall have a resistance of 1 ohm and power rating of at least 0·5 W.

A-2. dc System — The dc system consists of the dc supply and the dc electronic voltmeter.

A-2.1 dc Supply— The dc supply shall be stable and capable of supplying a suitable range of voltages. The actual supply voltage required is dependent on the value of the resistor under test (R_T), on the required test voltage (V_T), and on the value of the isolation resistor (R_m) as set out in Table 2. As a measure of the suitability of the power supply, the hum and noise interference introduced by the dc supply shall be less than 0·5 dB as indicated by the increase in the noise meter deflection when dc current is passed through a current noise free test resistor, such as a wire wound resistor.

A-2.2 dc Electronic Voltmeter — The voltmeter shall have a constant impedance of at least 4 megohms, in the frequency range from dc to 1 600 c/s. The time constant shall be less than 0·5 second. The meter, in conjunction with a step attenuator, shall be capable of indicating the required dc test voltages with an accuracy of ± 3 percent. The meter scales shall be calibrated in volts and in decibels (the 0dB reference being one Volt). Interference introduced by the voltmeter shall not produce an increase in the noise meter deflection greater than 0·2 dB when the voltmeter is connected to the input circuit.

A-2.3 Recommended Operating Conditions — The noise voltage (v_{rms}) is, in general closely proportional to the applied dc voltage (V_T). In order, however, to assure the most comparable measurements for all resistors and to assist in avoiding overloading components in the input circuit, it is recommended that Table 1 should be followed which gives recommended operating conditions for a wide range of values of test resistor. The recommended dc supply shall be capable of providing the voltages specified in Table 1. In case where the dc voltage or power recommended in Table 1 exceeds the continuous rating of the test resistor, the maximum rated value should be used in place of that specified in Table 2. Table 2 gives a set of operating conditions recommended for the testing of resistors having resistance values from 10 ohms to 22 megohms. At least four isolation resistors (R_m) are required (*see* **A-1.3**). These shall be current noise free (that is, good quality wire wound resistors) and the four decade values from 1 000 ohms to 1 megohm shall be included. Each isolation resistor shall have a power rating of at least 1W and the resistance tolerance shall be ± 1 percent.

TABLE 2 RECOMMENDED OPERATING CONDITIONS

(*Clauses* A-2.1 *and* A-2.3)

		0·5 W AND HIGHER WATTAGE RATINGS			1/4, 1/8 AND 1/10 W RATINGS		
R_T Ω	R_m Ω	D dB	V_T V	P_T MW	D dB	V_T V	P_T MW
100	1 k	10·1	3·2	100	10·1	3·2	100
120	1 k	11·6	3·8	120	10·9	3·5	100
150	1 k	13·5	4·7	150	11·8	3·9	100
180	1 k	15·1	5·7	180	12·5	4·2	100
220	1 k	16·9	7·0	220	13·4	4·7	100
270	1 k	18·3	8·2	250	14·3	5·2	100
330	1 k	19·2	9·1	250	15·1	5·7	100
390	1 k	19·9	9·9	250	15·8	6·2	100
470	1 k	20·7	10·8	250	16·7	6·9	100
560	1 k	21·4	11·8	250	17·5	7·5	100
680	1 k	22·3	13·0	250	18·3	8·2	100
820	1 k	23·1	14·3	250	19·2	9·1	100
1·0 k	1 k	24·0	15·8	250	20·0	10·0	100
1·2 k	1 k	24·8	17·3	250	20·8	11·0	100
1·5 k	1 k	25·8	19·4	250	21·7	12·2	100
1·8 k	1 k	26·6	21·2	250	22·5	13·4	100
2·2 k	1 k	27·4	23·4	250	23·4	14·8	100
2·7 k	10 k	28·3	26·0	250	24·3	16·4	100
3·3 k	10 k	29·2	28·7	250	25·2	18·2	100
3·9 k	10 k	29·9	31·2	250	25·9	19·7	100
4·7 k	10 k	30·8	34·3	250	26·7	21·7	100
5·6 k	10 k	31·5	37·4	250	27·5	23·7	100
6·8 k	10 k	32·3	41·2	250	28·3	26·1	100
8·2 k	10 k	33·2	45·3	250	29·1	28·6	100

(*Continued*)

TABLE 2 RECOMMENDED OPERATING CONDITIONS — *Contd*

		0·5 W AND HIGHER WATTAGE RATINGS			1/4, 1/8 AND 1/10 W RATINGS		
R_T Ω	R_m Ω	D dB	V_T V	P_T MW	D dB	V_T V	P_T MW
10 k	10 k	34·0	50·0	250	30·1	32·0	100
12 k	10 k	34·8	54·8	250	30·9	35·0	100
15 k	10 k	35·8	61·2	250	31·8	39·0	100
18 k	10 k	36·6	67·1	250	32·5	42·0	100
22 k	10 k	37·4	74·2	250	33·4	47·0	100
27 k	100 k	38·3	82·2	250	34·3	52·0	100
33 k	100 k	39·2	90·8	250	35·1	57·0	100
39 k	100 k	40·0	98·7	250	35·8	62·0	100
47 k	100 k	40·7	108	250	36·7	69·0	100
56 k	100 k	41·5	118	250	37·5	75·0	100
68 k	100 k	42·3	130	250	38·3	82·0	100
82 k	100 k	43·1	143	250	39·2	91·0	100
100 k	100 k	44·0	158	250	40·0	100	100
120 k	100 k	44·8	173	250	40·8	110	100
150 k	100 k	45·8	194	250	41·7	122	100
180 k	100 k	46·5	212	250	42·5	134	100
220 k	100 k	47·5	234	250	43·4	148	100
270 k	100 k	48·0	250	232	44·3	164	100
330 k	100 k	48·0	250	190	45·2	182	100
390 k	100 k	48·0	250	160	45·9	198	100
470 k	1 M	42·1	127	34·3	42·1	127	34·3
560 k	1 M	43·1	143	36·5	43·1	143	36·5
680 k	1 M	44·2	161	38·1	44·2	161	38·1
820 k	1 M	45·1	180	39·5	45·1	180	39·5
1·0 M	1 M	46·0	200	40·0	46·0	200	40·0
1·2 M	1 M	46·8	218	39·6	46·8	218	39·6
1·5 M	1 M	47·6	240	38·4	47·6	240	38·4
1·8 M	1 M	48·0	250	34·7	48·0	250	34·7
2·2 M	1 M	48·0	250	28·4	48·0	250	28·4
2·7 M	1 M	48·0	250	23·2	48·0	250	23·2
3·3 M	1 M	48·0	250	18·9	48·0	250	18·9
3·9 M	1 M	48·0	250	16·0	48·0	250	16·0
4·7 M	1 M	48·0	250	13·3	48·0	250	13·3
5·6 M	1 M	48·0	250	11·2	48·0	250	11·2
6·8 M	1 M	48·0	250	9·2	48·0	250	9·2
8·2 M	1 M	48·0	250	7·6	48·0	250	7·6
10 M	1 M	48·0	250	6·2	48·0	250	6·2
12 M	1 M	48·0	250	5·2	48·0	250	5·2
15 M	1 M	48·0	250	4·2	48·0	250	4·2
18 M	1 M	48·0	250	3·5	48·0	250	3·5
22 M	1 M	48·0	250	2·8	48·0	250	2·8

R_T = the resistor under test
R_m = the isolation resistor
D = $20 \log_{10} V_T$
V_T = the dc voltage across R_T
P_T = the power dissipated in R_T

A-3. ac Measuring System — The ac measuring system consists of a calibration source, an ac band-pass amplifier, a square-law detector, and an indicator.

A-3.1 Calibration Source — The calibration source, connected only during calibration, shall be a stable sine wave generator with a fixed frequency within the range 980 to 1 020 c/s. The output shall supply a voltage across the 1 ohm calibration resistor. The voltage shall be capable of being set within the range 0·6 to 0·7 millivolts and shall be stable to within ± 2·0 percent.

A-3.2 ac Band-Pass Amplifier, Square-Law Detector and Indicator

A-3.2.1 The amplifier gain shall be sufficient to measure circuit noise with the input terminals shorted and with the adjustable gain control described below set near its minimum gain position.

A-3.2.2 The circuit noise shall be not greater than that equivalent to the thermal noise of a 6·2 kΩ resistor; therefore, the increase in the output reading when the short is replaced by a 6·2 kΩ ± 5 percent resistor with no change in the setting of the gain control shall be at least 3 dB. The isolation resistors (R_m) shall be at least 100 kΩ and no dc current shall be present for this test.

A-3.2.3 The amplifier shall be capable of measuring input signals up to 650 microvolts. This signal amplitude gives a scale reading of approximately 60 dB when the system is calibrated.

A-3.2.4 A continuously adjustable gain control shall be provided for maintaining a fixed overall system gain which would otherwise vary with input conditions listed in Table 2. The necessary gain control range is approximately 33 dB.

A-3.2.5 The pass band shall be flat, shall have a fixed half power pass band of approximately 1 000 c/s within the limits ±50 c/s and shall be geometrically centred at 1 000 ±50 c/s. Ripple in the flat top of the pass band shall not exceed ±0·2 dB.

A-3.2.6 These requirements should be satisfied for all measurement conditions listed in Table 1. Neither the value '*A*' as determined in 3 nor the half power pass band shall vary with respect to measurement condition by more than ±4 percent for any recommended measurement condition. Compliance at 100 ohms and 22 megohms is considered sufficient.

A-3.2.7 The ac amplifier, square-law detector, and indicating meter shall respond to noise signals without introducing significant error due to clipping. This requires the dynamic range to extend at least 10 dB beyond the indicated rms value.

A-3.2.8 The ac measuring system shall be calibrated in dB from −20 to at least +60 dB with 0 dB being one microvolt in a frequency decade. The accuracy of the detector and meter shall be ±0·4 dB. The time constant shall be from 0·8 to 1·5 seconds.

A-4. Function Switch — It is convenient to have a three-position switch to provide the three modes of operations (*see* **A-4.1** to **A-4.3**) normally followed in the measurement procedure (*see* **4**).

A-4.1 Calibration — At this setting the isolation resistor (R_m) is connected to ground instead of to the dc supply. At the same time, the setting supplies the 1 000 c/s calibration voltage across the calibration resistor.

A-4.2 Measurement of System Noise — At this setting the calibration voltage is removed while all other connections remain as in **A-4.1**.

A-4.3 Measurement of Total Noise — At this setting the R_m terminal, which was grounded for the settings described in **A-4.1** and **A-4.2**, is connected to the dc supply instead of to the ground, and as a result, dc voltage is supplied to the resistor under test. No calibration voltage is present.

INTERNATIONAL SYSTEM OF UNITS (SI UNITS)

Base Units

Quantity	*Unit*	*Symbol*
Length	metre	m
Mass	kilogram	kg
Time	second	s
Electric current	ampere	A
Thermodynamic temperature	kelvin	K
Luminous intensity	candela	cd
Amount of substance	mole	mol

Supplementary Units

Quantity	*Unit*	*Symbol*
Plane angle	radian	rad
Solid angle	steradian	sr

Derived Units

Quantity	*Unit*	*Symbol*	*Definition*
Force	newton	N	1 N = 1 kg.m/s^2
Energy	joule	J	1 J = 1 N.m
Power	watt	W	1 W = 1 J/s
Flux	weber	Wb	1 Wb = 1 V.s
Flux density	tesla	T	1 T = 1 Wb/m^2
Frequency	hertz	Hz	1 Hz = 1 c/s (s^{-1})
Electric conductance	siemens	S	1 S = 1 A/V
Electromotive force	volt	V	1 V = 1 W/A
Pressure, stress	pascal	Pa	1 Pa = 1 N/m^2

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